Institute for Maintenance Science and Technology

ATMOSPHERIC PLASMA FOR SURFACE MODIFICATION

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Materials Science and Engineering
www.imst.us

NC STATE UNIVERSITY

ASETS DEFENSE
ADVANCED SURFACE ENGINEERING TECHNOLOGIES FOR SUSTAINABLE DEFENSE
ASETSDefense'11: Sustainable Surface Engineering for Aerospace and Defense
February 8-10, 2011
New Orleans, Louisiana
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SERDP
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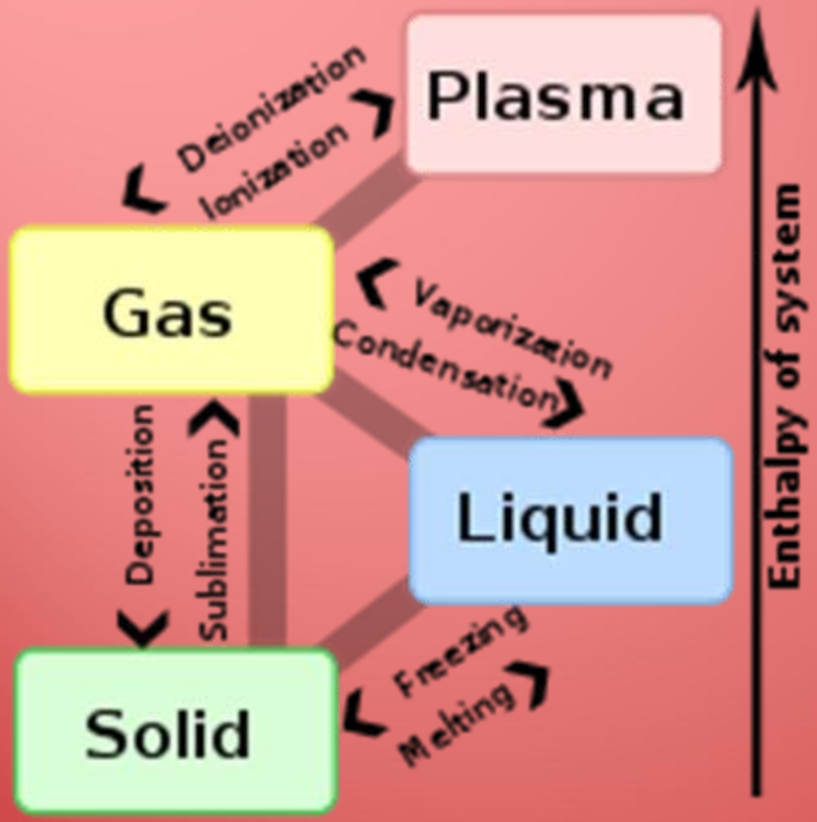
Brief

- Atmospheric Plasma Explained
- Applications of Cold Plasma
- Commercial Devices
- Examples

4th State of Matter



www.wikipedia.com

>95% of matter in the universe is Plasma

Plasma generated by
- Heat
- Voltage
- EMR
- Laser
- Nuclear reactions

Atmospheric Plasma processing occurs at atmospheric pressure

Parallel Plate

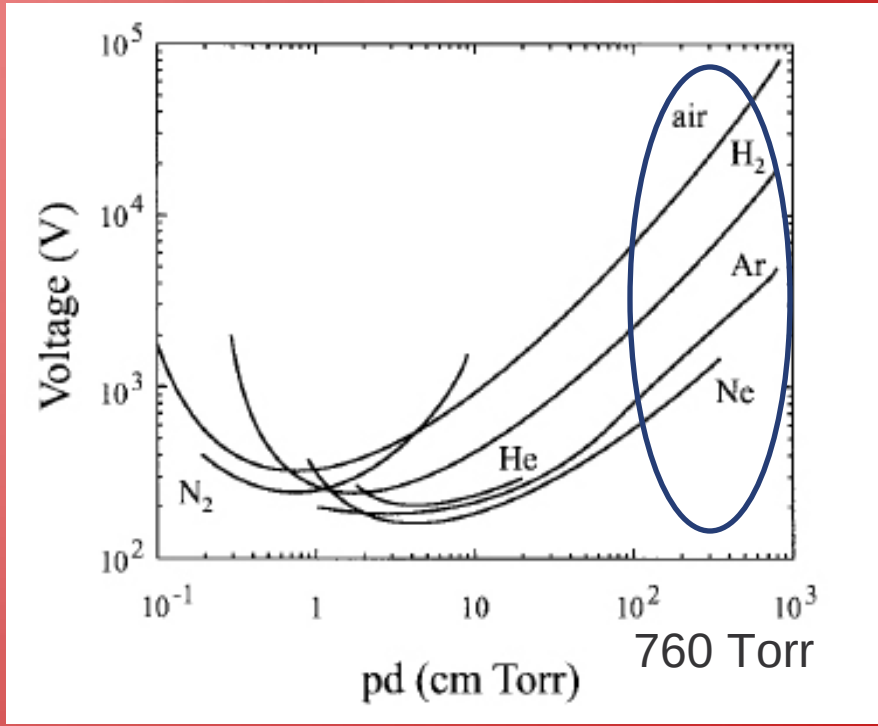
Paschen's Law (1889) governs the breakdown of gas between plates

$$V = \frac{a(pd)}{\ln(pd) + b}$$

V = breakdown voltage
p = pressure
d = distance between electrodes

a and b are constants dependent on gas

$$pd = e^{1-b}$$



Paschen curves for common gases

Schultz, IEEE Trans.Plasma Sci (26)6 1998

Plasma Classification

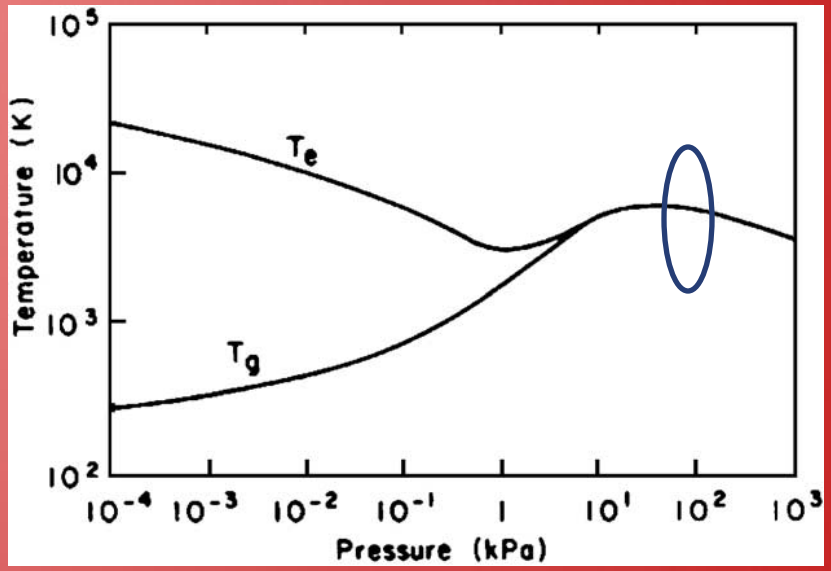
- Equilibrium vs. Non-Equilibrium

  LTE = Local Thermodynamic Equilibrium

  Te = Tg

  Te = electron temperature

  Tg = gas temperature



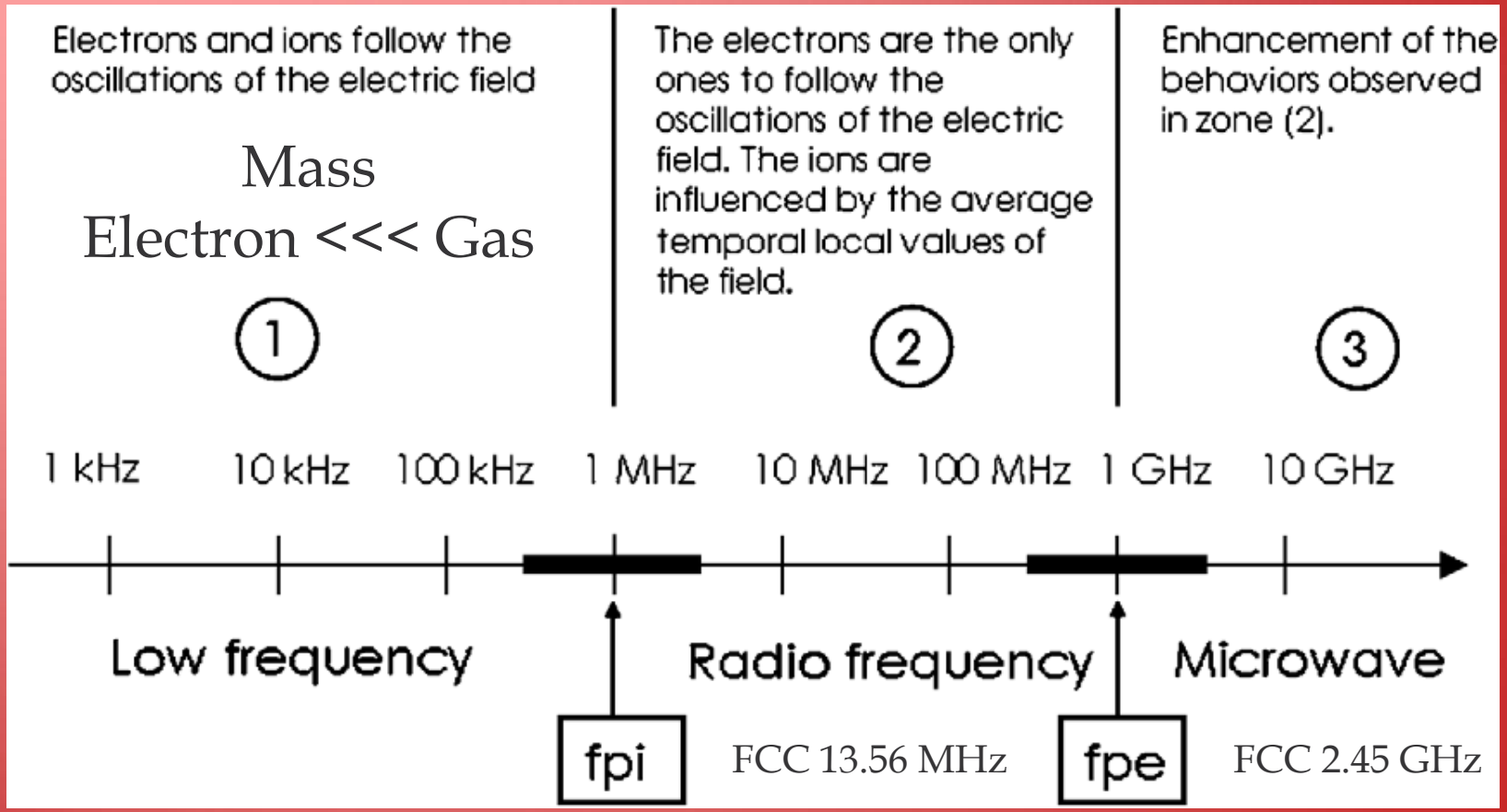
- Thermal vs. Cold Plasma

(arc transition)
Ion/neutral temperature
and degree of ionization

Tendero Spectrochim Acta B 2006

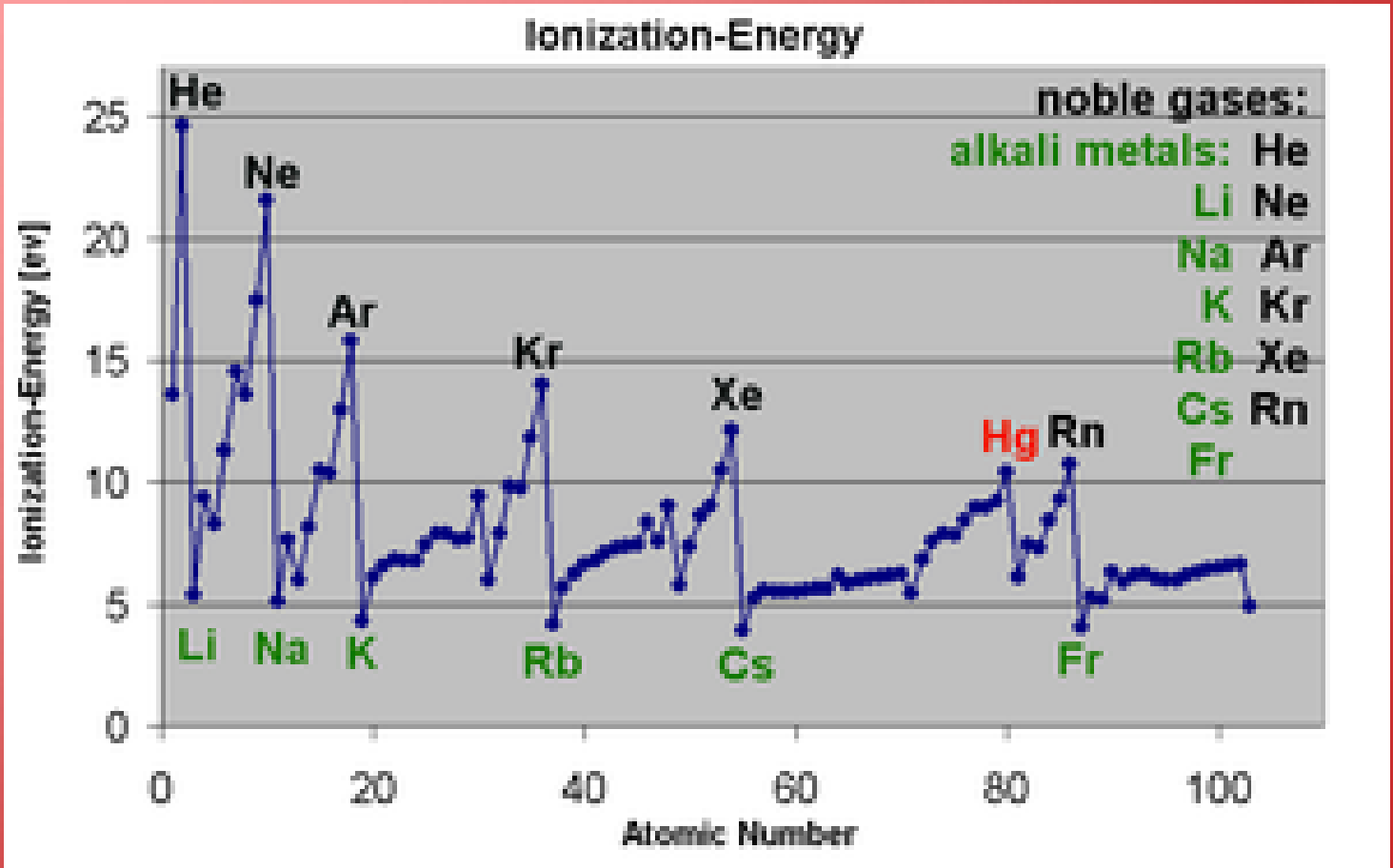
1 atm	101.325 kPa (N/m2)	1.01325 Bar	760mm Hg	760 Torr	14.696 psi

Frequency Effects



Tendero Spectrochim Acta B 2006

Ionization Energy vs. Atomic Number



Wikipedia.org

Plasma Composition

- Neutrals
  - He, Ar, O_2, N_2, H_2,CO_2
- Free electrons
- Positive and negative ions
- Stable and meta-stable active species
- Monatomic and polyatomic species
- Radicals

Examples

- $O_2 + e^- = O_2^+ + 2e^-$
- $O_2 + e^- = O_2^-$
- $O_2 + e^- = O^* + O + e^-$
- $O + O_2 = O_3$
- $O_3 + H = OH + O_2$
- $N + O_2 = NO + O$
- $H + O_2^- = OH^- + O$

Free electron density vs. electron Temperature

IMST

Applications

- Cleaning down to the atomic level

  Finger oils, silicone oils, hydraulic fluid, sizing, solder flux, carbon soot, machining fluids, mold release agents

- Treatment

  Cross linked barrier coatings, dry low friction surfaces

- Deposition

  Polymerized hydrocarbon coatings, chemical barriers, scratch resistant coatings, glass-like surfaces, diamond like films

Applications

- Oxidation/reduction

  Organic and inorganic functionalities

- Activation.

  Hydroxyl, carboxylic, carbonyl, amine, vinyl, thio functionalities

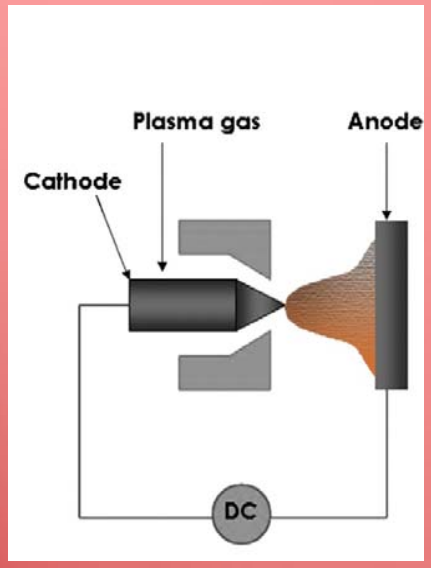
- Adhesion enhancement

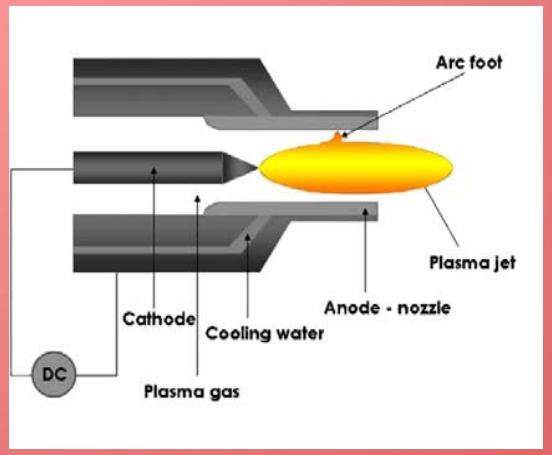
  Grafting of functional groups, hydrophobic or hydrophilic surface

Biomedical Applications

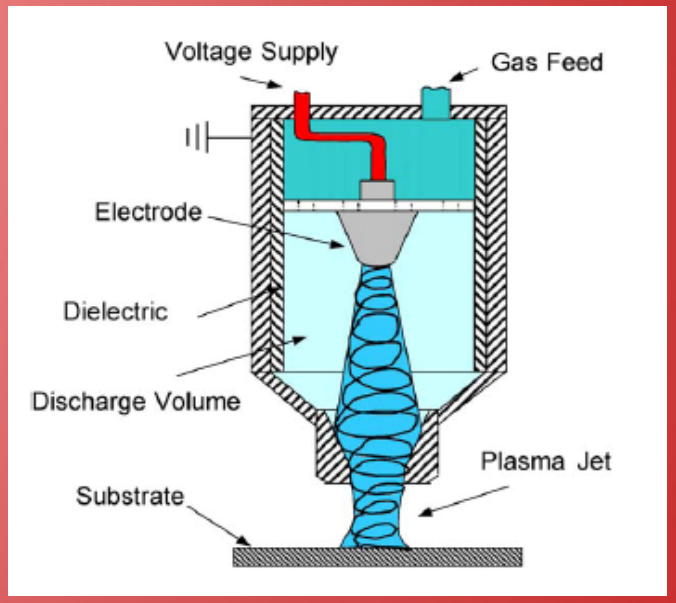
- Sterilization of medical devices and implants
- Air decontamination and biocides
- Antiseptic, fungicide, disinfection
- Bio-functional sites for subsequent attachment of cells, proteins, drugs, bio-conjugated polymers
- Food and food processing disinfection
- Textile chemistry

"Torch" Schematics





Transferred Arc **Pilot Arc**



Schematic of **Hot DC** plasma devices

Tendero Spectrochim Acta B 2006

Schematic of a **Cold AC** plasma device

C. Noeske, Int.J.Adh.Ad. (24) 2004

Atmospheric Plasma "Torches"

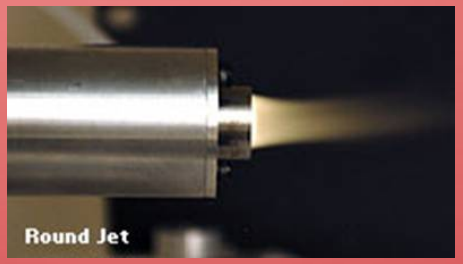
Diener
Plasma beam

PVA Tepla
Plasma Pen

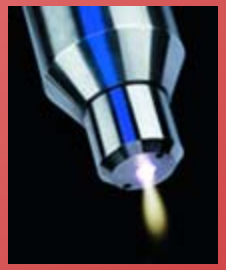
AcXys
ULS

Enercon
Dynamite IT

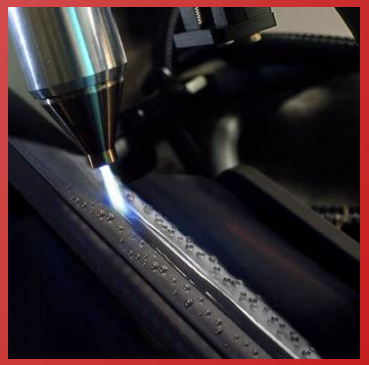
AP Solutions
Plasma Flux



Apjet
Round Jet

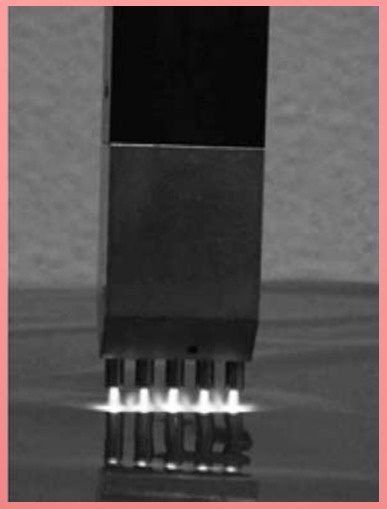


Plasmatreat
FixedJet

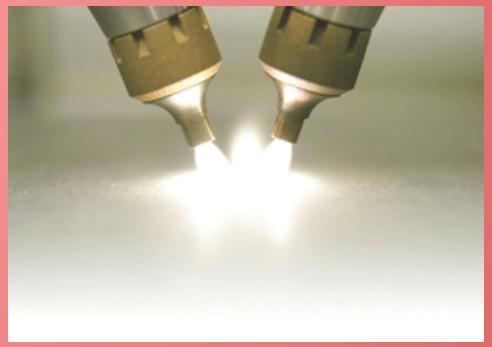


Plasma dyne

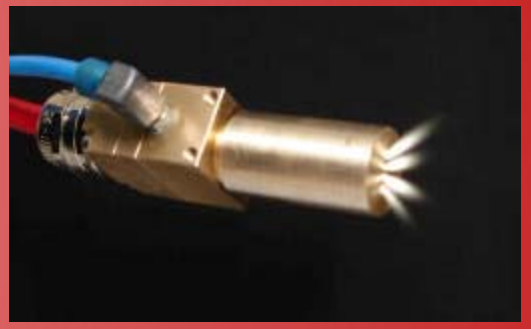
Multiple Nozzles



PVA Tepla
Plasmapen

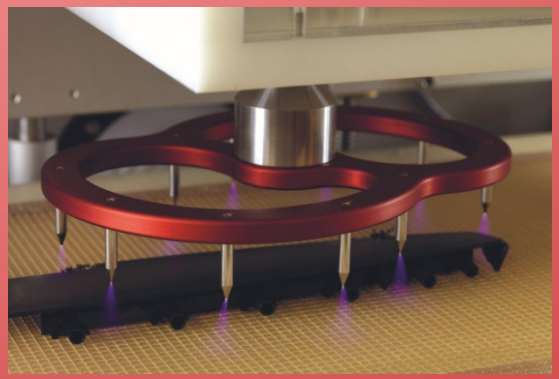


Diener
Dual Beam



AcXys
ULS

Tantec
MonTEC

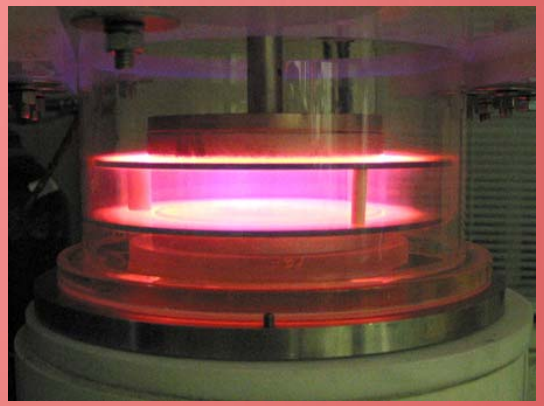


Tantec
corona

www.bmfd.de

Parallel Plate

AP Solutions



NCSU DBD

Fraunhoffer

Enercon Plasma VCP

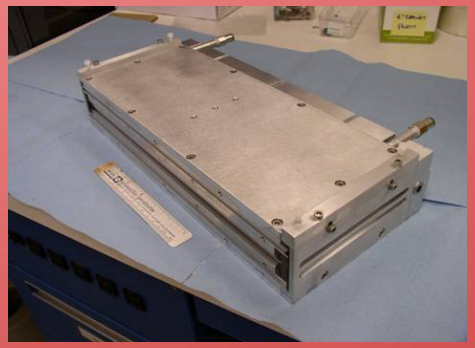
One Atmosphere Uniform Glow
IEEE Trans. Plasma Sci. 2007

Linear Arrays

Enercon
Plamsa3 VCP

Tantec
SpotTEC

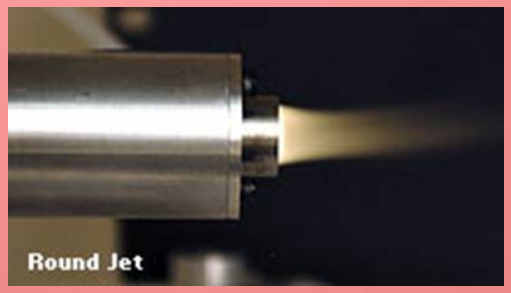
Enercon
DynaAMite



Apjet
Flatjet

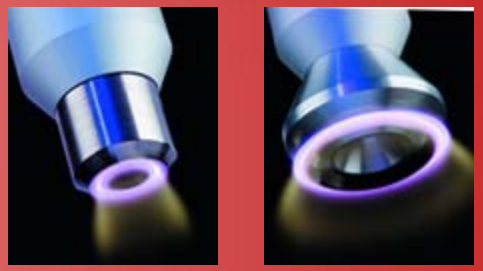
Apjet
Texjet

Alternate Geometries



Apjet
Round Jet

Surfx
Atomflo

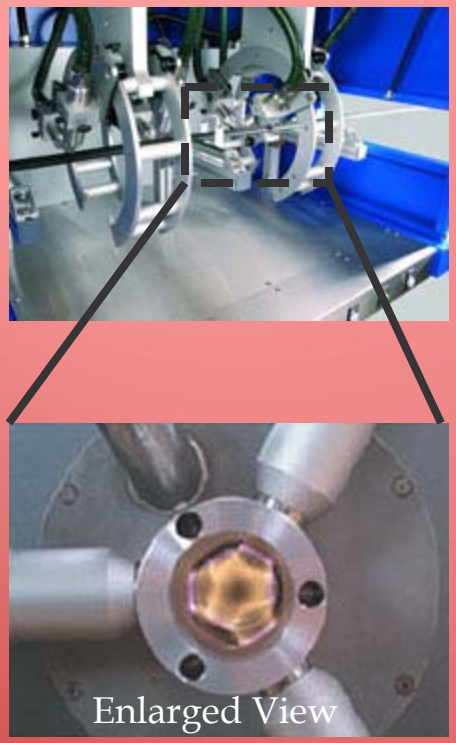


Plasmatreat
RotaryJet

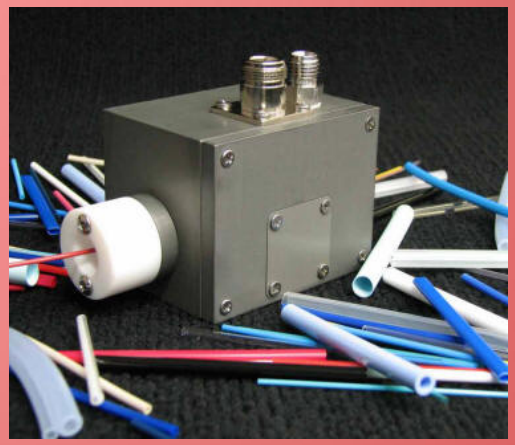
Surfx
Atomflo

Iplas
Cyrannus

Continuous Profiles

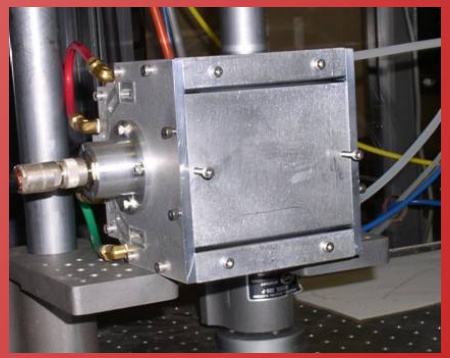


PlasmaTreat
Profile tunnel



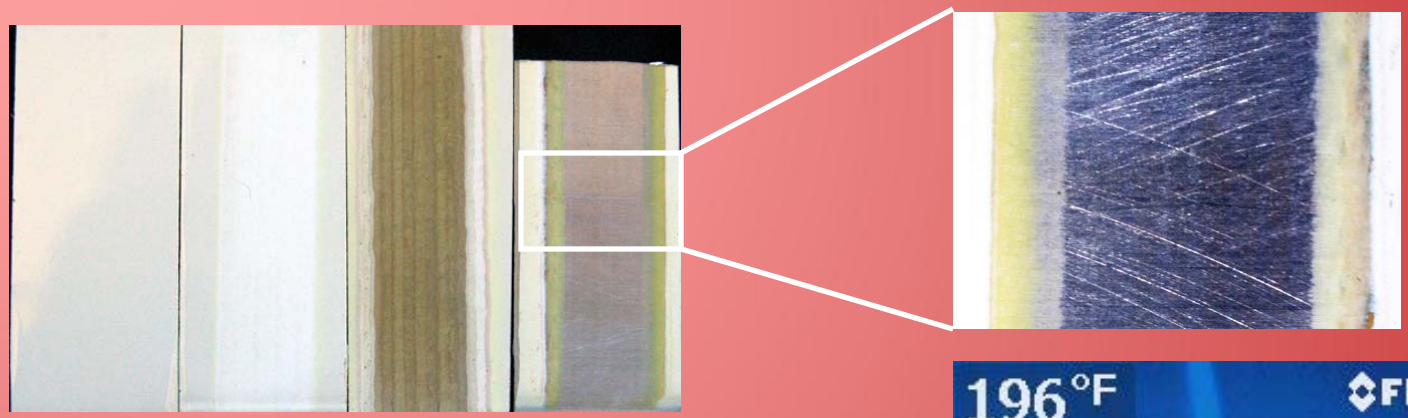
Surfx
Atomflo 400T

Tantec
CableTEC

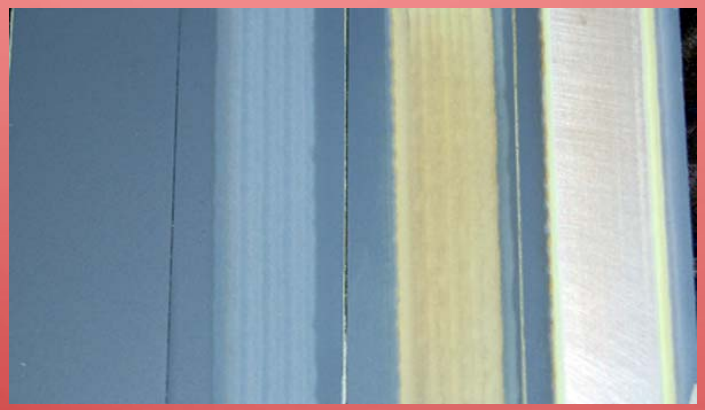


Apjet
Rollerjet

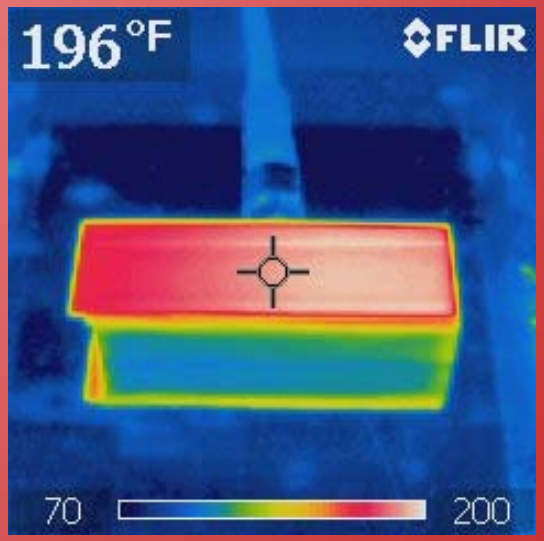
Plasma Paint Removal



Enlarged View

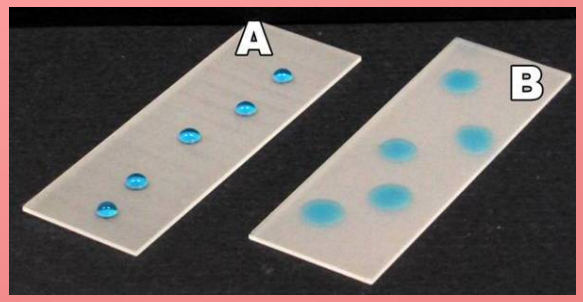


Layered paint removal from 1”x 3” coupons
MIL 85285/23377 on 2024Al



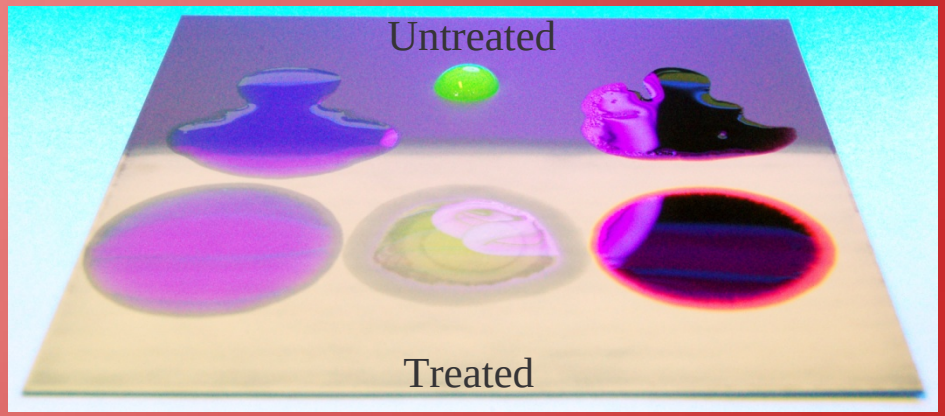
Infrared image
after treatment

Plasma Treatment Increases Surface Energy



A: Hydrophobic surface before treatment
B: Hydrophilic surface after treatment

Hydraulic fluid Water Mineral oil
MIL 83282



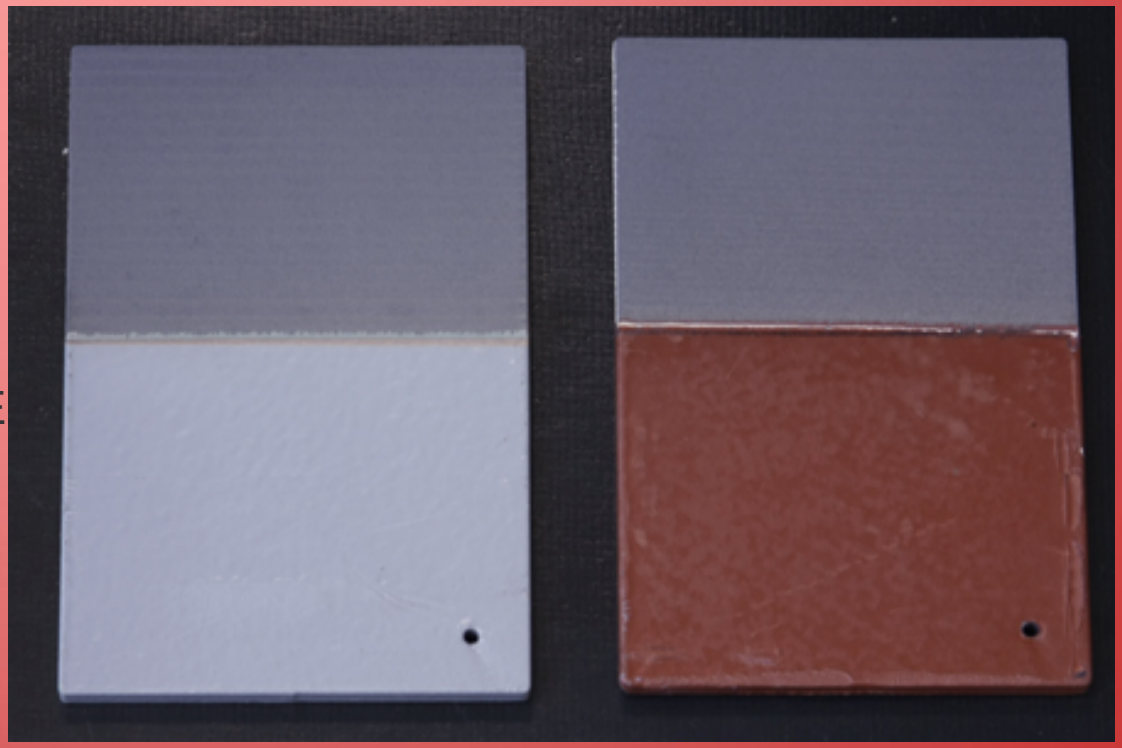
Fluid drops with fluorescent dye on MIL85285 polyurethane painted aluminum illuminated with a black light

Dyne solutions and contact angles can be used to measure surface energy

NAVSEA Paint

After
Plasma

Before
MIL PRF 24635E
Haze Grey
MIL DTL 24443
Epoxy Primer



After
Plasma

Before
MIL 24647
Anti-Fouling
MIL DTL 24443
Epoxy Primer

SSPC SP-10/NACE2 Mild Steel

Si Alkyd Ablative Paint/Steel

Panel subjected to
Seawater Immersion

Base metal after
atmospheric plasma

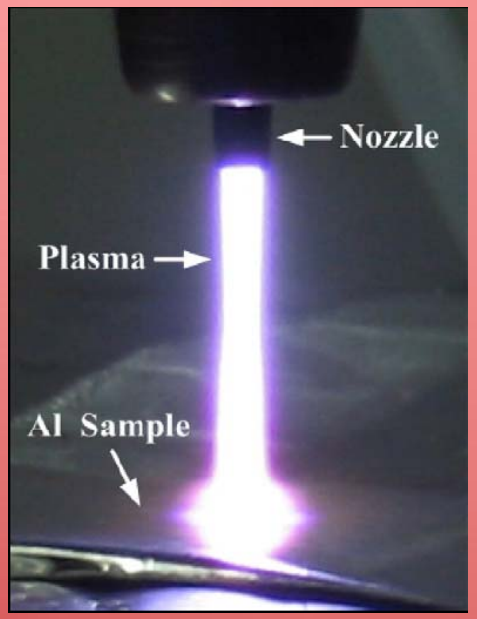
Plasma Sealant Removal from Fasteners

Before

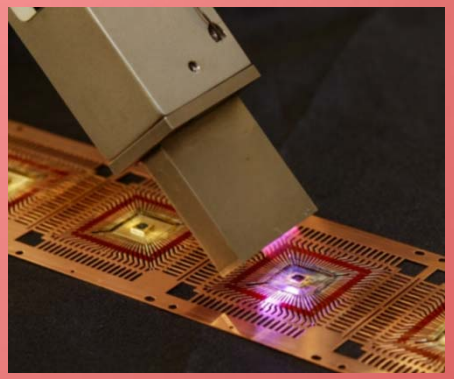
After

MIL-PRF-81733 Polysulfide

Oxidation and Reduction



D.H. Shin "μWave Plasma"
Surface & Coating and Technology 201 (2007)



SurfX
Atomflo

AcXys

Surfx
H2 Plasma

Plasma Electrolytic Polishing and Oxidation

(Micro Arc Oxidation)

- Solid, Liquid, Gas, and Plasma
- Higher voltages than conventional anodizing: 200 V <
- Acidic or alkaline aqueous solutions oxide thickness < 100μm
- Crystalline oxides
  Hard, tough: Al, Mg, Ti

Keronite.com

Summary

- Atmospheric Plasma is complex
- Numerous applications both for Oxidation and for Reduction
- Rapid Advancement in Applications
- Fundamental Understanding is Lacking

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- *"Manufacturing Improvement Processes"* ONR # N00014-08-1-0124

- *PPG Desoto, AC TECH*

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NCSU De-paint Video